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Advanced Fueling
Infrastructure Pillar
INL/MIS-19-53675

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Fueling Infrastructure for Future Shared and Shared-Automated Vehicles

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Idaho National Laboratory
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Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
BERKELEY LAB
OAK RIDGE National Laboratory
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Overview

Timeline

- Start: October 2016
- End: September 2019
- 85% Complete

Budget

- Total: $2,160K
- FY19: $740K
  - INL: $410K
  - NREL: $155K
  - ANL: $50K
  - LBNL: $125K
- FY18: $900K
- FY17: $520K

Barriers

- Infrastructure requirements and impacts are not yet understood for electric shared mobility
- High risk to develop and deploy advanced vehicles and infrastructure

Partners

- SMART Mobility Laboratory Consortium partners: INL (lead), NREL, ANL, LBNL
- Data Partners:
  - Populus
  - INRIX
  - RideAustin
  - Yellow Cab of Columbus

Relevance to VTO Goals

U.S. DEPARTMENT OF ENERGY

Advanced Fueling Infrastructure Pillar

- Transportation electrification has significant potential to increase mobility energy productivity, *provided that* adequate charging infrastructure is available
- The Advanced Fueling Infrastructure Pillar is focused on understanding the costs, benefits, and requirements for charging infrastructure to support energy efficient mobility systems of the future

The Question that is Vexing Decision Makers

What charging infrastructure do we need for electric ride-hailing vehicles in the future?

April 12, 2018

EVgo and Maven Gig Announce Nation's First Dedicated Fast Charging Network for On-Demand Drivers

WAMU, AUG 14, 2017

With No Place To Charge, D.C.'s Electric Cab Drivers Ask For Help

District's Eco-Friendly Cab Program Suffers From Lack Of Charging Stations

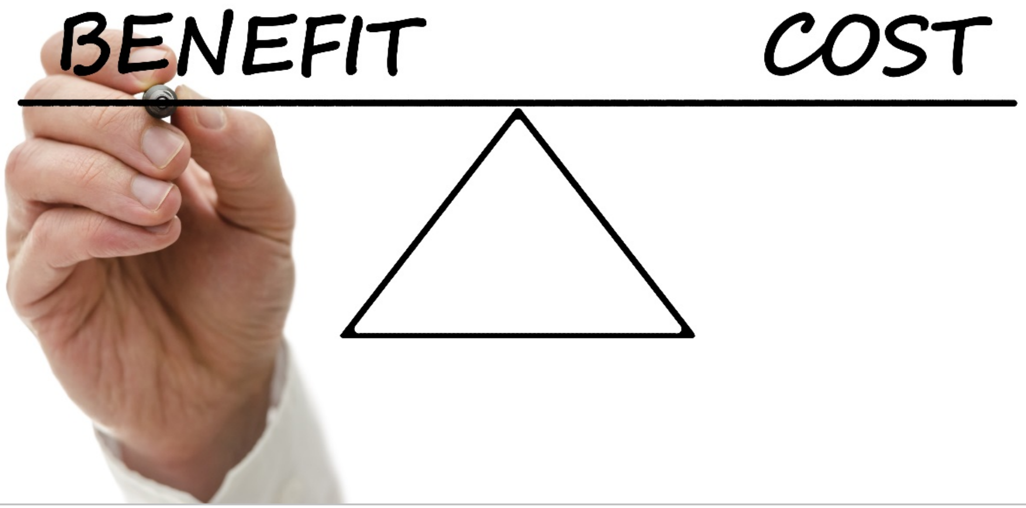
Source: shutterstock.com

Source: INL

https://wamu.org/story/17/08/14/no-place-charge-d-c-s-electric-cab-drivers-ask-help/
https://www.evgo.com/about/news/evgo-maven-gig-announce-nations-first-dedicated-fast-charging-network-demand-drivers/

Answer

- There is no “right” amount of charging infrastructure
- Different amounts and types afford different levels of service to different market segments
- What we need is a way to quantify trade-offs



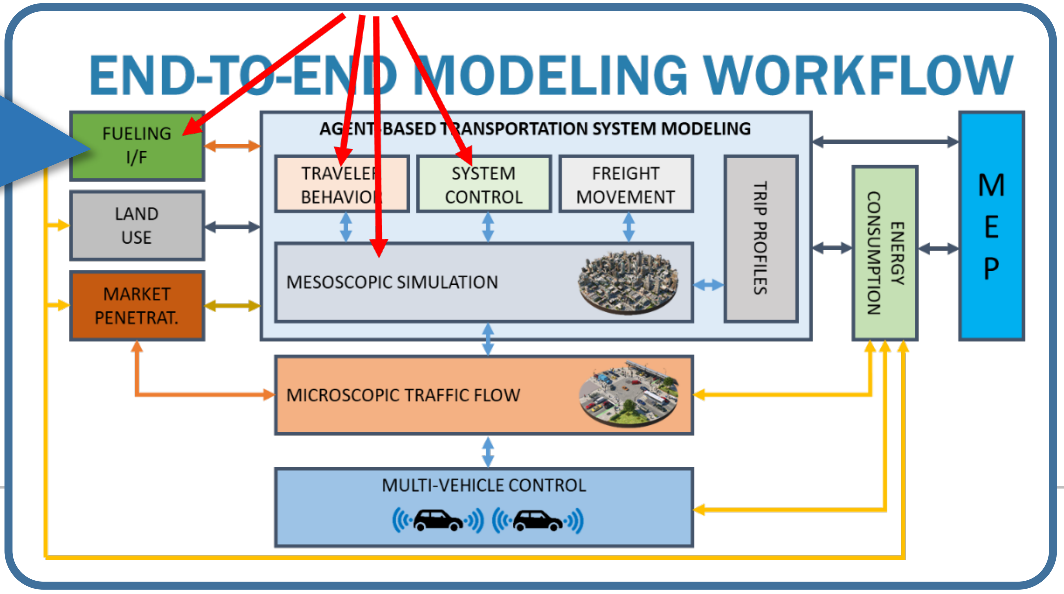
Fueling Infrastructure for Future Shared and Shared-Automated Vehicles

Project Objectives

- Examine the charging needs of shared and shared-automated EVs
- Understand trade-offs between charging infrastructure coverage, utilization, and mobility
- Highlight to industry and municipalities the value of different approaches to charging infrastructure network design to support shared mobility

Our work is a key part of the SMART Mobility workflow

We are here



Approach

FY17/18 AFI2.1

Human-driven ride-hailing EVs

Charging network simulation using EVI-Pro with real-world data from ride-hailing company

Austin, TX case study

FY17/18 AFI2.3

Automated electric ride-hailing EVs

Charging network simulation using BEAM agent-based modeling platform

SF Bay Area case study

Idealized cases

Centrally-planned charging networks that satisfy all demand without queueing

FY19 AFI2

Alternative infrastructure planning approaches with realistic constraints that serve defined market segments

Transportation simulation in BEAM to see trade-offs between charging network design and level of service

Realistic cases

Quasi-centrally-planned charging networks with constrained resources

Project Milestones

Quarter	Milestone	Status
FY18 Q4	Energy consumption and economic evaluation of PEVs vs. ICEVs, inclusive of fueling infrastructure costs	Complete
FY19 Q1	Define customer use cases and align with SMART Mobility common scenarios	Complete
FY19 Q2	Complete charging behavior models for ride-hailing fleets	Complete
FY19 Q3	Incorporate charging behavior models and infrastructure planning approaches into BEAM	In progress
FY19 Q4	Issue report on trade-offs inherent with different approaches to charging infrastructure planning for future mobility	In progress

Technical Accomplishments

1. Charging infrastructure planning with BEAM for automated electric vehicle (AEV) taxi fleet in the Bay Area
2. Charging infrastructure planning with EVI-Pro for human-driven ride-hailing EVs in Austin
3. Total cost of ownership analysis for human-driven ride-hailing EVs in Austin
4. Behavioral segmentation to better define use cases
5. Determining charging behavior of ride-hailing EV drivers
6. Optimizing charging behavior for AEVs

Charging Infrastructure Planning with BEAM for AEV Taxi Fleet in the San Francisco Bay Area

BEAM Simulation

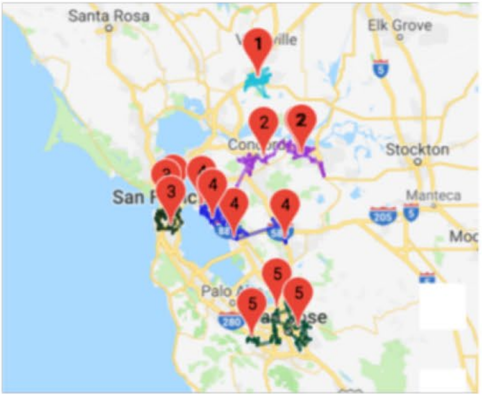
Simulate driving, parking & charging behavior of AEVs; Charge when state of charge drops below threshold

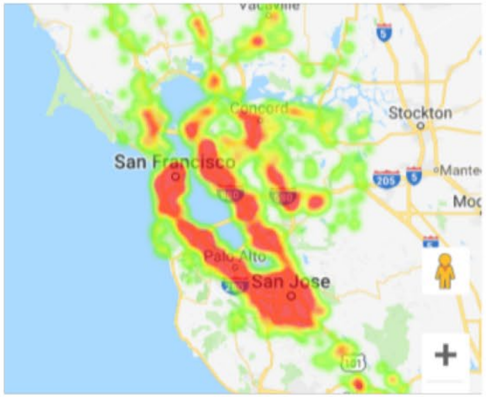
Charging Demand

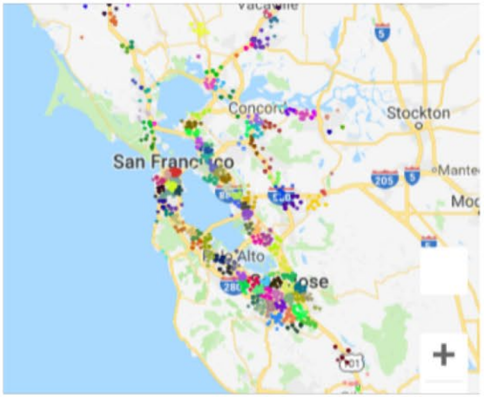
Record when and where charging demand occurs in the system

Station Planning

Locate charging stations to satisfy all charging demand, subject to quality of service constraints



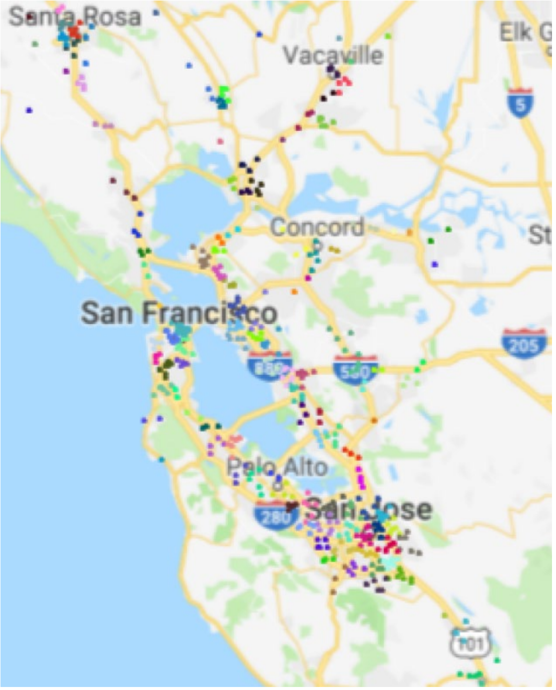




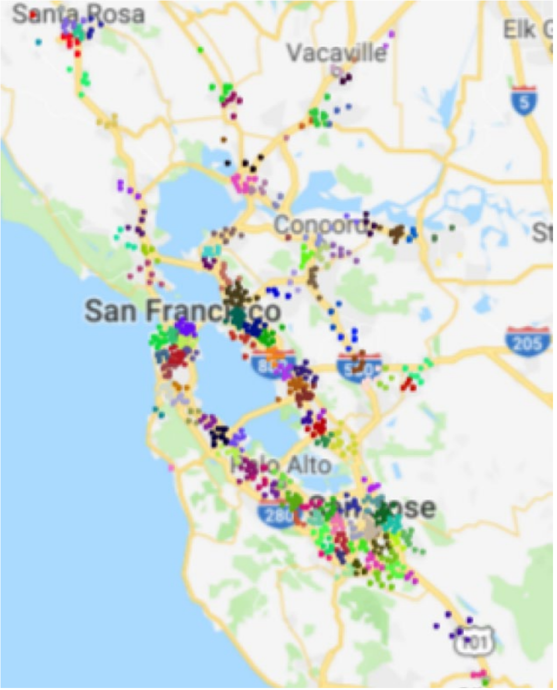
Source: Zhang, H., Shepard, C., Lipman, T., Zeng, T. & Moura, S. (2019). “Charging Infrastructure Demands of Shared-Use Autonomous Electric Vehicles in Urban Areas.” Submitted to Transportation Research Part D.

Charger Siting to Meet Demand in Two Scenarios

- Dots represent 50-kW DC fast charger sites to serve fleet of BEV150s
- Geographic coverage of chargers is about the same, regardless of fleet size



Fleet size: 5,000 vehicles

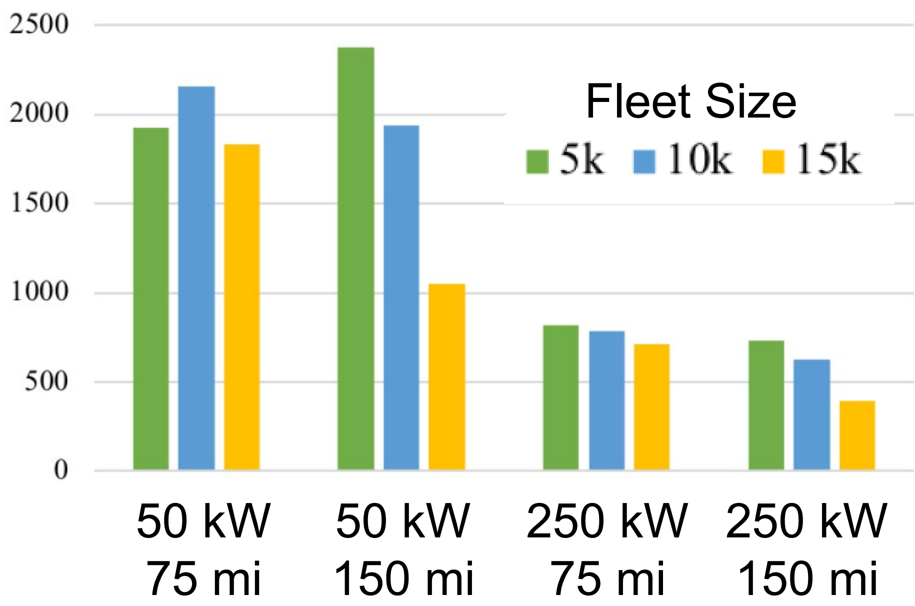


Fleet size: 15,000 vehicles

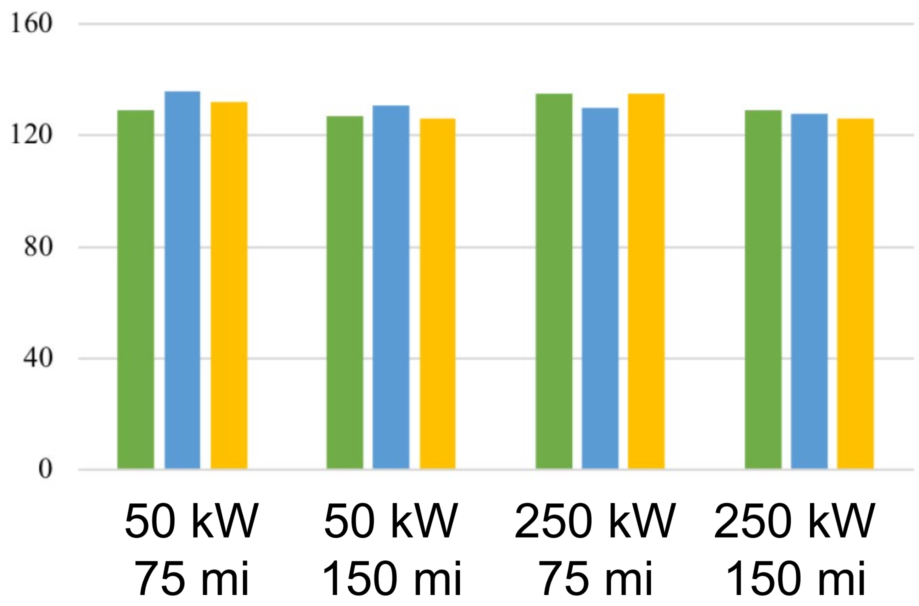
Charger Siting to Meet Demand in Multiple Scenarios

- The number of *charge points* is highly sensitive to the level of power of the charge network, as well as the relative fleet size
- The number of *charging stations* is fairly fixed to provide adequate geographical coverage

Number of Chargers

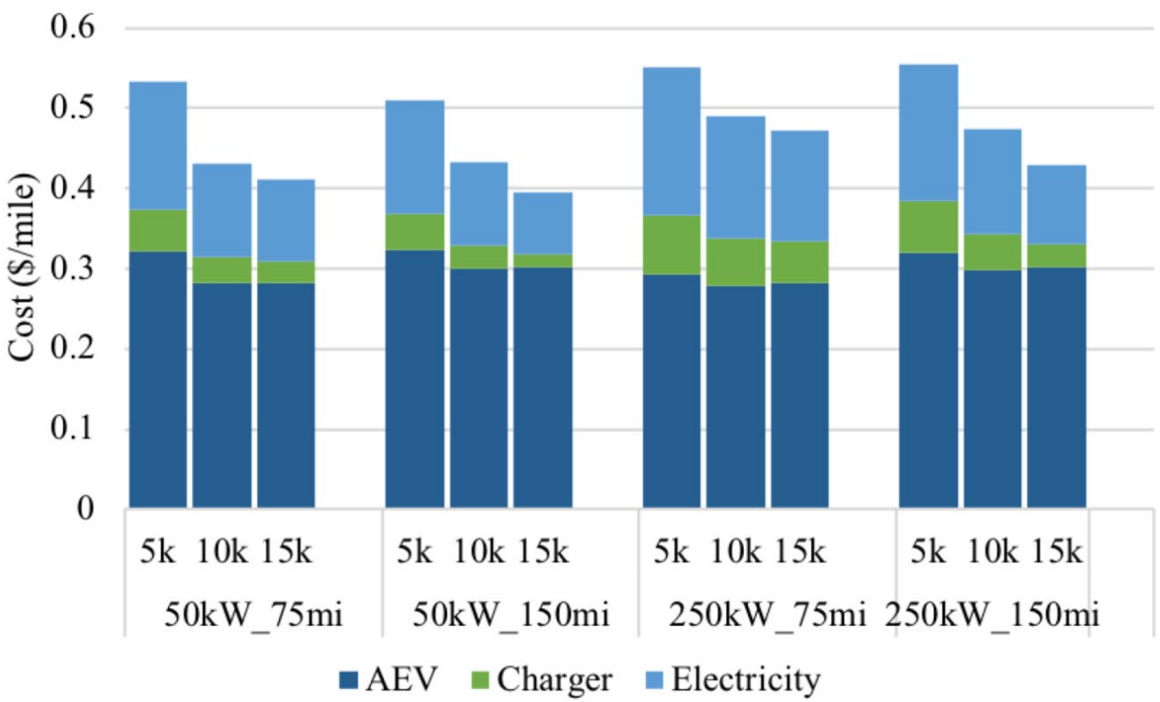


Number of Charging Stations



Economic Analysis of Multiple Scenarios

- Larger fleets of AEVs can serve travel demand with lower per-mile cost
- Cases with 50-kW charge networks seem to perform significantly better economically than with 250-kW charge networks
- 150-mile range AEV fleets slightly out-perform 75-mile range vehicles



Charging Infrastructure Planning with EVI-Pro for Human-driven Ride-hailing EVs in Austin

- Illustrative scenarios from EVI-Pro simulation of full-time RideAustin drivers

All drivers have home charging

Simulated Results	"Yesterday"	"Today"	"Tomorrow"
EV Driving Range	100 mi	250 mi	400 mi
DCFC Power	50 kW	150 kW	400 kW
DCFC Plugs per 1000 BEVs	60	10	5
Daily DCFC Participation Rate	30%	2%	1%

DCFC requirements per BEV decrease as driving range increases. Almost all charging needs are satisfied with home charging alone

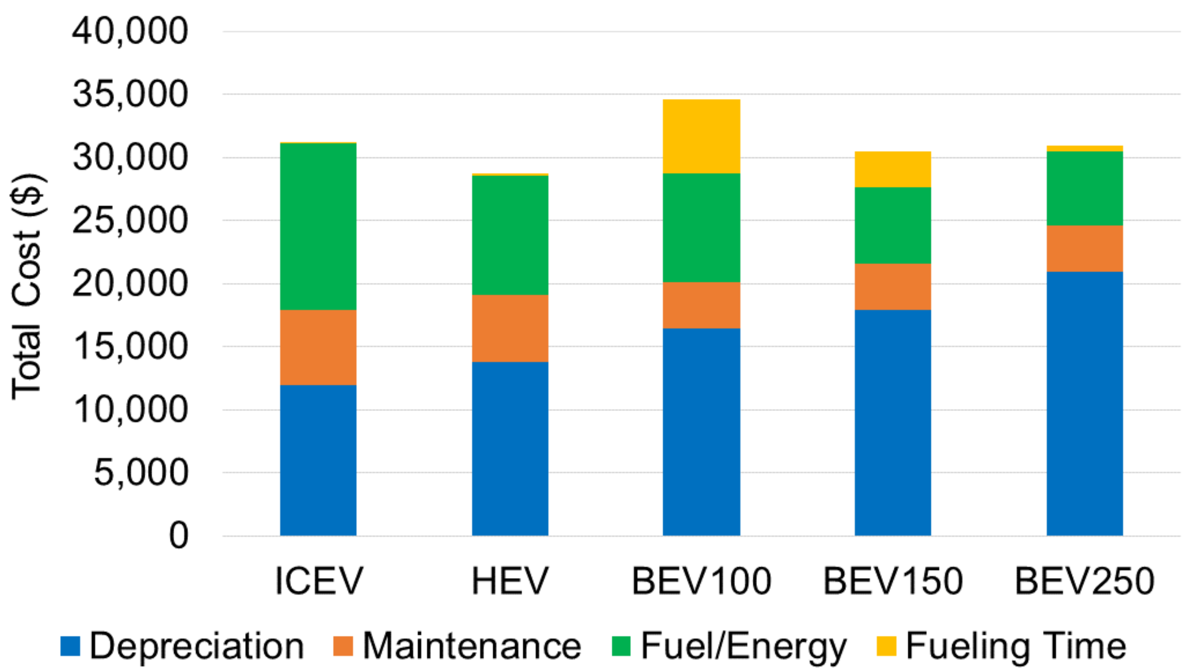
"Tomorrow" with varied home charging access

Simulated Results	100% home	53% home	53% home, no public L2
Simulated DCFC Plug Count	48	356	604
DCFC Plugs per 1000 BEVs	5	36	60

Reduced home charging access significantly increases the need for public charging infrastructure

Total Cost of Ownership Analysis for Human-driven Ride-hailing EVs in Austin

- Total cost of ownership of EVs, ICEVs, and HEVs as ride-hailing vehicles
- Opportunity cost of fueling/charging during shift included (yellow)
- BEV150, BEV250 have same cost as ICEV

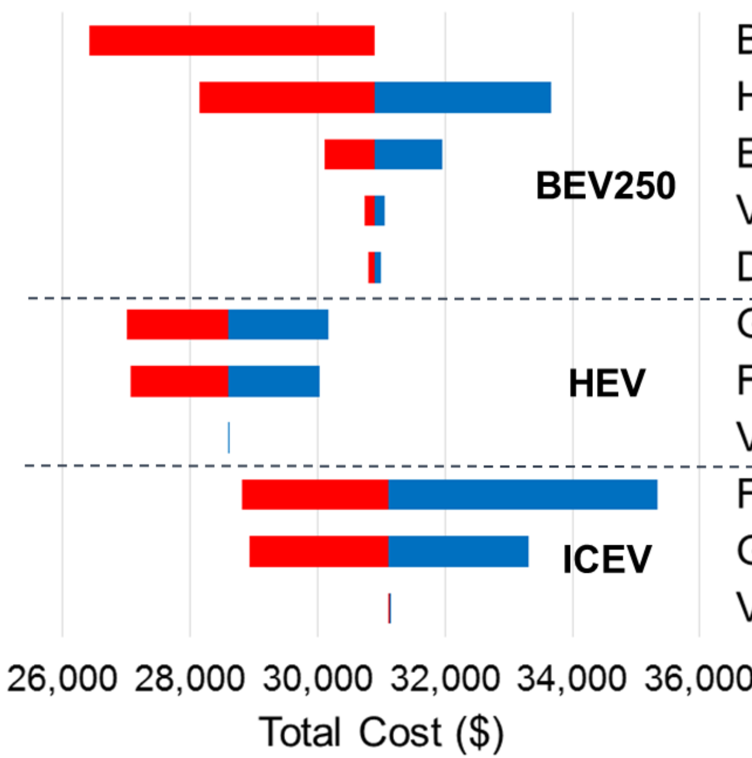


Assumptions:

- Avg full-time driver: 29k mi/yr
- 5 year ownership period
- No travel time or queueing time to charge
- All drivers charge at home

Ownership Cost Variation for Human-driven Ride-hailing EVs in Austin

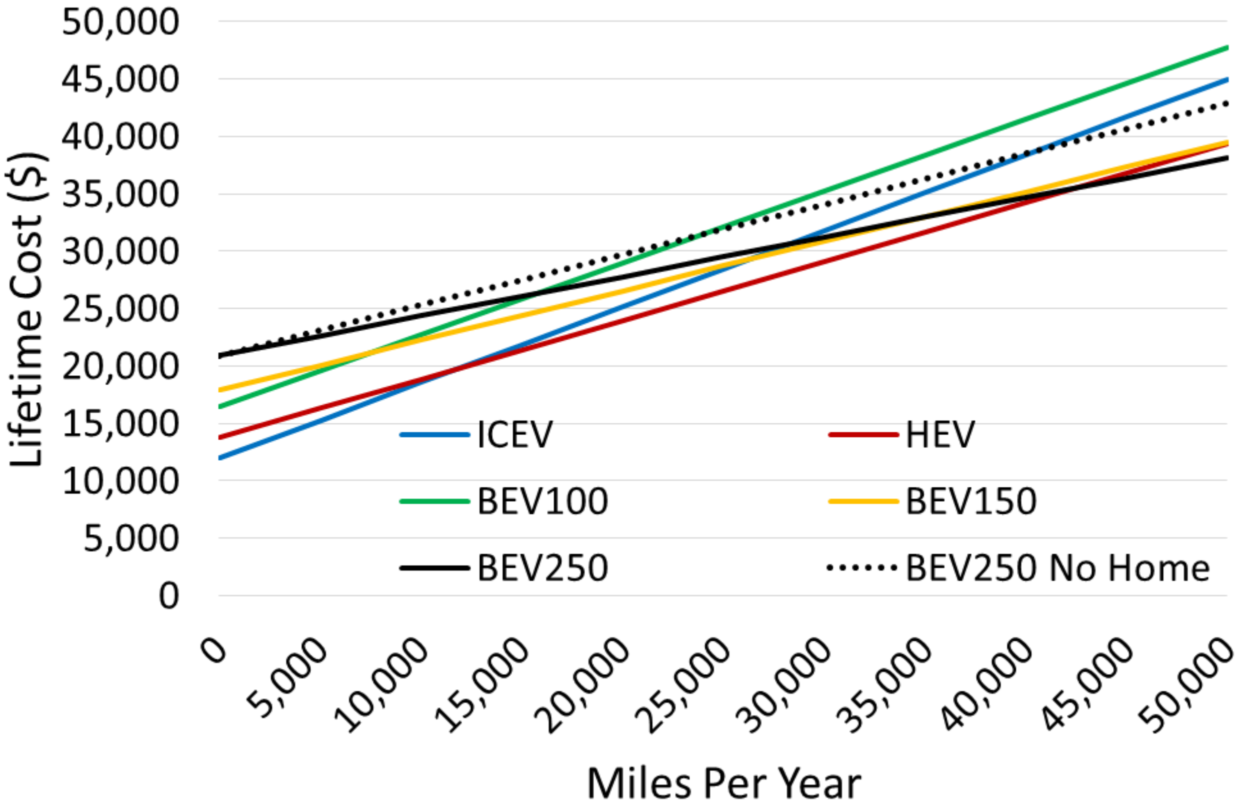
- Wide variation in potential costs from vehicle characteristics, energy costs, incentives, etc.
- Use case definition becomes very important



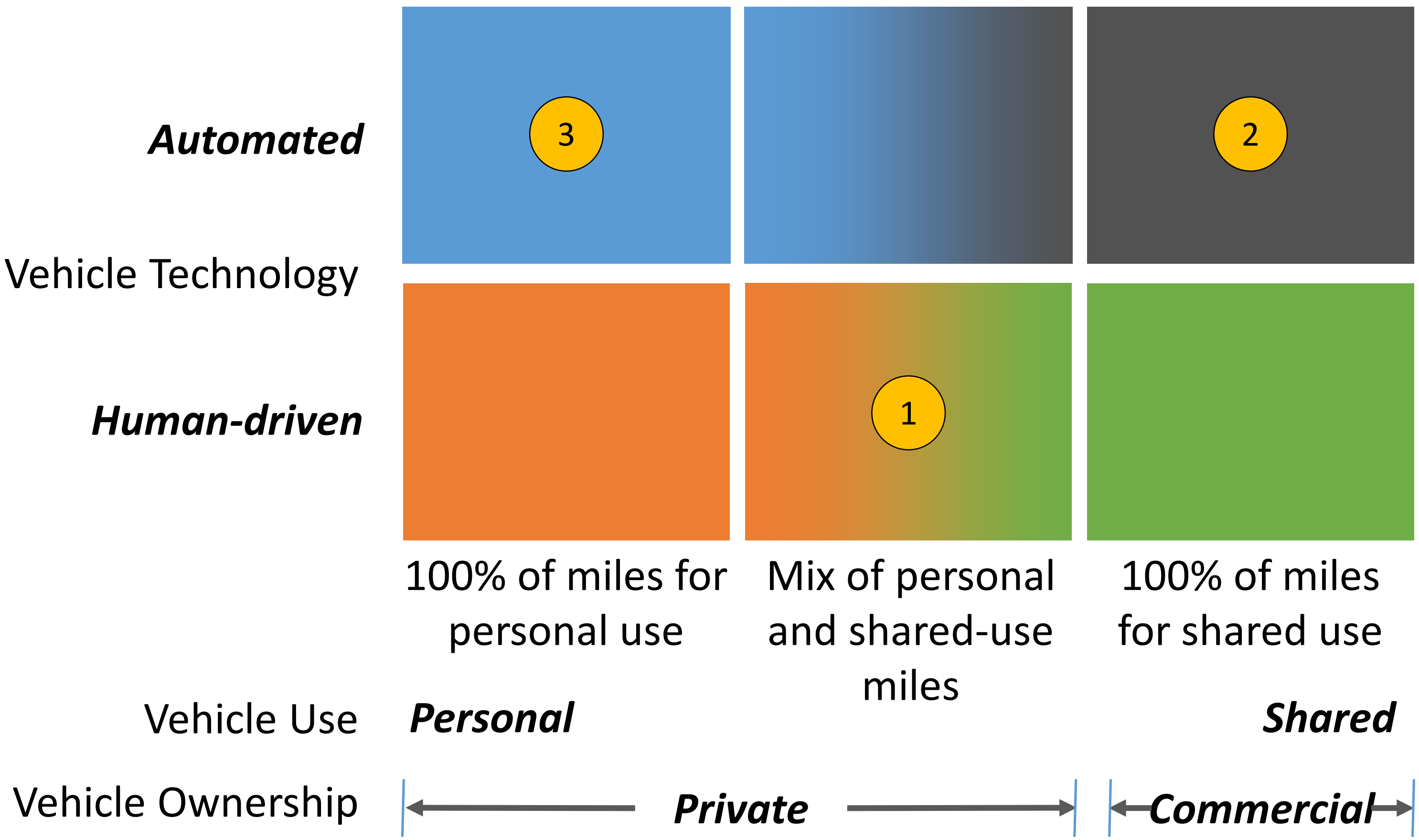
		Low Cost	Base-line	High Cost
BEV250	BEV Purchase Rebate, $	7500	0	0
	Home Electricity Price, $/kWh	0.06	0.13	0.20
	EV Fuel Economy, Wh/mi	250	285	333
	Value of Time, $/hr	10	15	20
	DCFC Price, $/kWh	0.30	0.40	0.50
HEV	Gas Price, $/gal	2.50	3.00	3.50
	Fuel Economy, MPG	55	46.1	40
	Value of Time, $/hr	10	15	20
ICEV	Fuel Economy, MPG	40	33	25
	Gas Price, $/gal	2.50	3.00	3.50
	Value of Time, $/hr	10	15	20

Ownership Cost Variation for Human-driven Ride-hailing EVs in Austin

- BEVs do not have lower overall cost in some cases
- Need to be thoughtful about EV adoption assumptions



Behavioral Segmentation to Better Define Use Cases



Prevalent use case in three SMART Mobility common scenarios

Modeling Charging Behavior of Ride-hailing EV Drivers

- Driver and fleet operator charging behavior and preferences must be taken into account
- Focus on two EV operator segments:

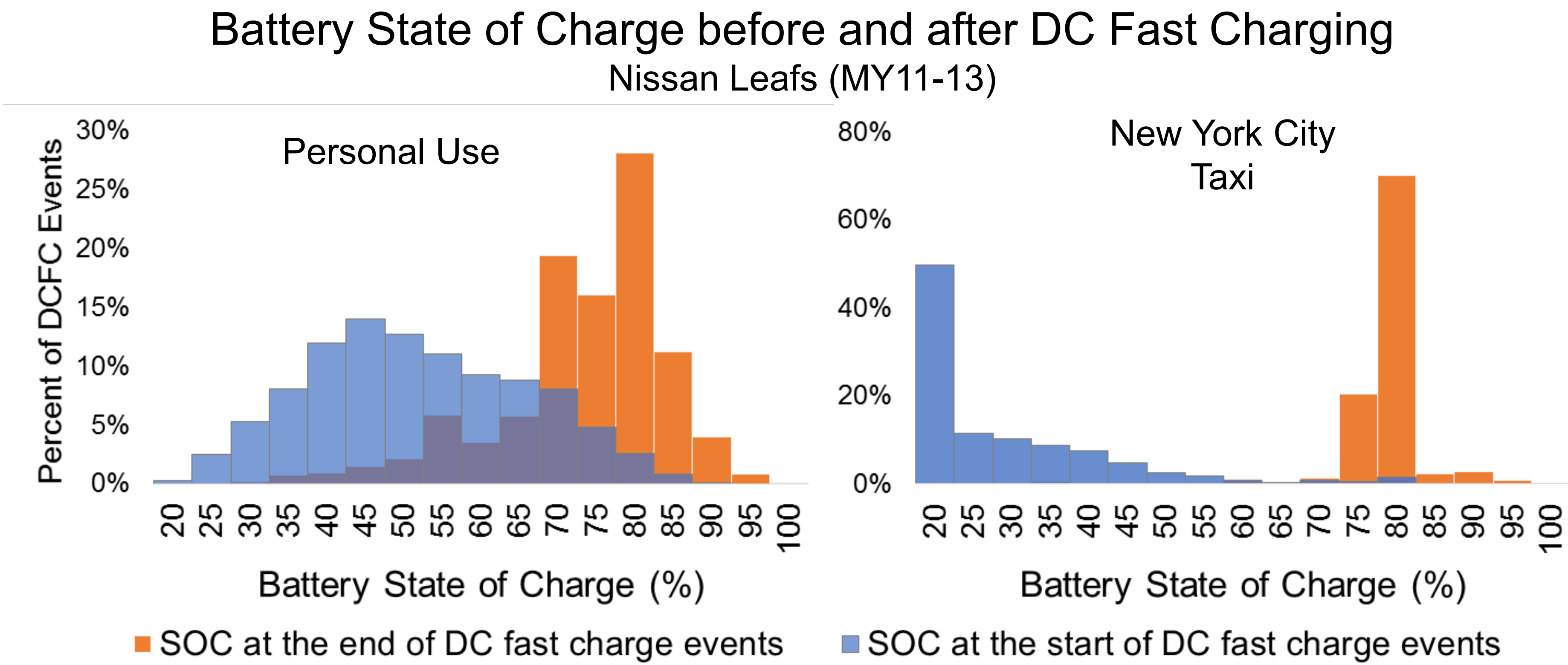
Privately-owned, human-driven EVs operated for both personal and shared use

Source: AP Photo/Jeff Chiu

Commercially-owned, automated EVs operated solely for shared use

Source: waymo.com

Driver Charging Behavior: Fast Charging

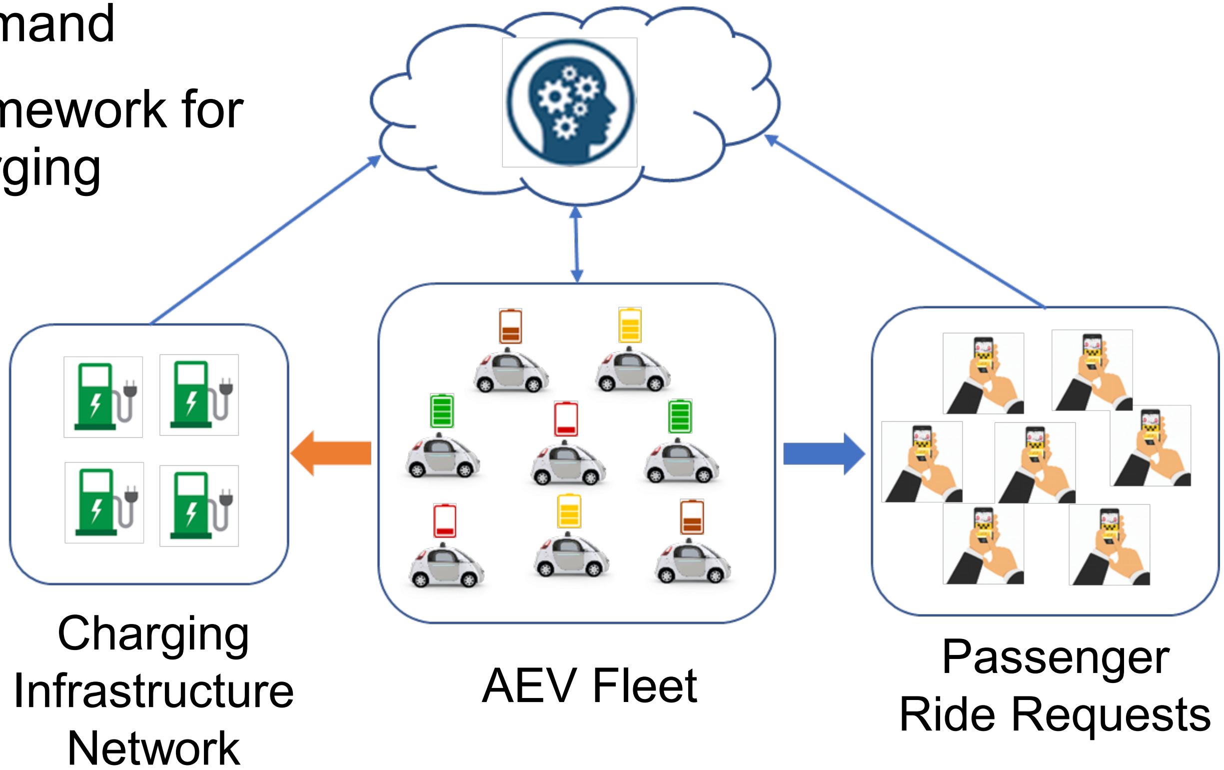


- Taxi drivers tended to deplete battery more than personal-use-only drivers prior to fast charging and they nearly always fully charged (i.e., to at least 80% SOC)
- Opportunity cost of charging motivates taxi drivers to use chargers more efficiently

Determining Charging Behavior for Commercially-owned AEVs

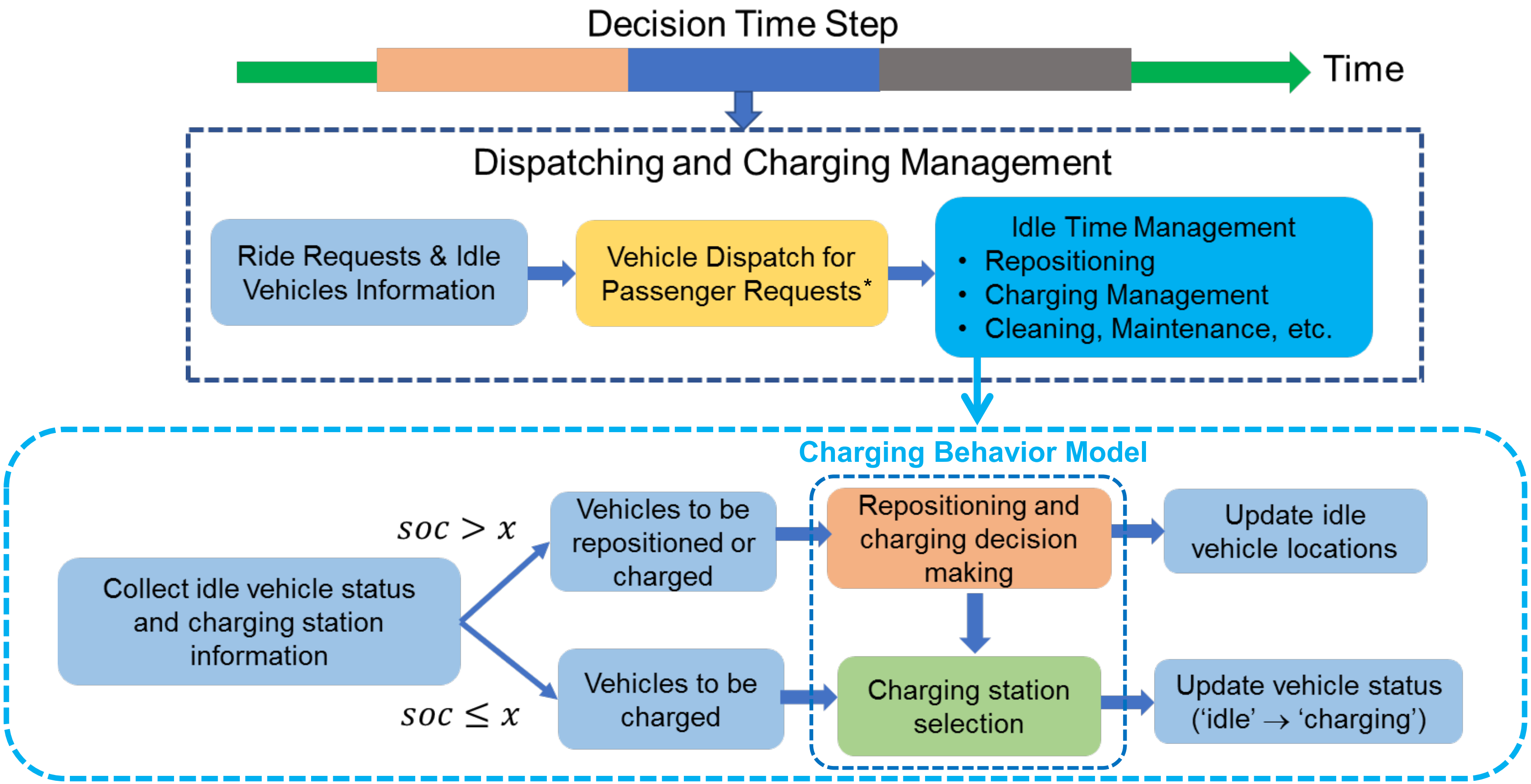
Factors that influence charging decisions

- Available infrastructure
- Passenger travel demand
- Decision-making framework for dispatching and charging management



Source: INL

Decision-Making Framework for Dispatching and Charging Management of Commercially-owned AEVs



Source: INL

* Vehicle dispatch system architecture to fulfill passenger requests is outside the scope of this project. We are using an architecture already developed, such as Zhe Xu, et al. "Large-scale order dispatch in on-demand ride-hailing platforms: A learning and planning approach." *Proceedings of the 24th ACM SIGKDD* ACM, 2018.

Proposed Future Research

Remaining research in FY19

- Develop alternative approaches to planning charging infrastructure that have realistic constraints
- Implement charging network and charging behavior models in BEAM
- Create and execute simulation plan that addresses multiple use cases and sensitivities
- Analyze cost/benefit trade-offs
- Disseminate results

Any proposed future work is subject to change based on funding levels

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- The approach is appropriate, and the team has done an excellent job given the limited data availability.
  - Data availability continues to be challenging, so we are doing our best to rationalize reasonable scenarios and assumptions, in coordination with the broad SMART Mobility Laboratory Consortium
- The project relies on the assumption that the adoption of shared vehicles with EVs could be substantial enough to overwhelm the existing/planned infrastructure for non-shared vehicles…. Projecting shared vehicle growth rates and EV adoption rates (both shared and non-shared) would provide suitable reference points to predict the potential impact.
  - We are using the consortium's common scenario assumptions for EV adoption
- The reviewer said that for shared mobility applications, it would be valuable to determine the impact of satisfactory and unsatisfactory levels of infrastructure on EV usage for privately owned ridesharing vehicles. In addition, the change in behavior of ride operators/owners to availability of charging would be beneficial.
  - This is the objective of the project. FY19 simulation will specifically address both of these points.
- The reviewer said it could be useful to include other alternative fuels with lower operating costs at some point.
  - Based on VTO guidance, the team decided to focus exclusively on electric vehicles in FY17-19 work

Collaboration and Coordination

DOE SMART Mobility Laboratory Consortium participants:

- Idaho National Laboratory
  - Use case development, charging behavior modeling, charging infrastructure network design, and cost modeling
- National Renewable Energy Laboratory
  - Data collection, analysis, and simulation of shared-mobility data to determine usage patterns and infrastructure needs of shared EVs
- Argonne National Laboratory
  - Charging infrastructure network design and cost modeling
- Lawrence Berkeley National Laboratory
  - BEAM development for specific use cases, simulation, and trade-off analysis

Data partners: Populus, INRIX, RideAustin, Yellow Cab of Columbus

Remaining Challenges and Barriers

- The future of shared mobility and its impact on travel requires further research
  - Technologies and markets are rapidly advancing
  - Complex business partnerships and business models are evolving rapidly that will change critical assumptions
  - To keep up, lab researchers conducted stakeholder interviews with
    - Maven
    - Cruise Automation
    - ReachNow
    - Ford Motor Co.
    - Marain Inc.
    - Yellow Cab of Columbus
    - New York City Taxi and Limousine Commission
    - Every Uber and Lyft driver to ever give us a ride
- Behavioral economics factors, such as public charging pricing elasticity, will likely have a large impact on behavior, but these are difficult to model due to lack of data

Summary Slide

- There is no “right” amount of charging infrastructure
- The focus should be on managing the trade-off between level of service, cost, and mobility
- Must define use cases carefully: different market segments have different behavior and motivations
  - Access to home charging is highly influential factor
  - Fleet size, vehicle range, and charge power level all impact charging demand
- The best is yet to come: comprehensive simulation to be run in 2nd half FY19 will show impact of charging network design on mobility

Any proposed future work is subject to change based on funding levels

QUESTIONS?

TECHNICAL BACK-UP SLIDES

Notes for BEV100 State of Charge Distributions

Notes for BEV100 Personal Use / DC Fast Charging

- Nissan Leafs (MY11-13) in 19 US metro areas
- ~1,000 Leafs using 50-kW DCFC in 2013
- Many BEV drivers did not use DCFC during study period
- Distribution based on 7,901 charging events

Notes for BEV100 NYC Taxi / DC Fast Charging

- Data from 5 Nissan Leaf taxis (MY11-12) in NYC
- Drivers had access to two 50-kW DCFCs and no home charging
- Distribution based on 469 charging events

We are here

END-TO-END MODELING WORKFLOW